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BODY COMPOSITION AND NUTRITION IN SKIING

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ABSTRACT

Special requirements, such as super-maximally filled glycogen stores, short regeneration times, correct meal timing or appropriate weight specifications for ski jumping are particularly useful for endurance athletes such as cross-country skiers. A deficiency could have a fatal effect on performance and possibly a negative influence on health.

While cross-country skiing is clearly one of endurance sports, ski jumping and alpine skiing are considered to be fast-strength sports or technical (acrobatic) sports.

The proven advantages of carbohydrate loading (supercompensation), a nutritional technique for classic endurance loads, also apply to cross-country skiing.

A drop in performance, concentration and coordination disorders as well as overheating threaten if fluid loss exceeds 2% of the total body water. Vitamin additives or sweeteners in sports drinks are inefficient. Since the higher need is actually compensated by the increased food intake with a balanced mixed diet, there is, in principle, no over-proportional need for individual vitamins in athletes.

As the maximum oxygen uptake is already 15% lower from 3000 m altitude, a drop in performance is clearly noticeable there.

When skiing (snowshoeing, ski touring, etc.), it should be noted that an ascent of 100 meters in altitude alone requires an additional 100–150 kcal. At moderate activity, the additional energy requirement at high altitudes compared to the sea level is estimated to be 250–290 kcal per day for men and 180–200 kcal per day for women.

Top athletes in cross-country skiing can liberate 170–210 kJ/min (40–50 kcal/min) in a dominant anaerobic manner within 2–3 minutes. The respective energy consumption is modified by numerous personal as well as external

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factors (for cross-country skiing, for example, the outside temperature, the friction resistance of the snow, the technique, the height profile of the route and the headwind).

In cross-country skiers, the average values of body fat range between 4.8 and 12.7% in males and from 10.6 to 22.7% in females, while the average values of lean body mass (LBM) vary between 58.2 and 68.8 kg in males and from 45.6 to 48.6 kg in females. In alpine skiers, the mean values of body fat are between 9.7 and 15.8% in males and from 16.2 to 26.7% in females, and the LBM values in males range between 59.9 and 74.7 kg, in females from 42.1 to 52.8 kg. The span of body fat in male ski jumpers ranges from 8.6 to 16% with an LBM of 59.7 kg. Since 2012, a BMI of at least 21 kg/m^2 including suit and shoes has been a condition for ski jumpers to be able to use full-length skis (145% of body height). Otherwise, shorter skis have to be used, which reduces the wing area and is intended to reduce the jump distance as a penalty. The average values of body fat in male athletes of Nordic Combined range between 8.9 and 11.2%, and the corresponding LBM values are between 62.0 and 64.1 kg. When comparing these parameters of body composition, it must always be remembered that different methods of determining the body fat percentage have been used in corresponding studies and that possible differences do not represent a development of the skiing somatotypes over time but could also have methodological reasons.

Keywords: *body composition; nutrition; cross-country skiing; alpine skiing; ski jumping*

INTRODUCTION

Since the first Winter Olympics in 1924, ski jumping and cross-country skiing have been represented among the competitive disciplines.

Alpine skiing has been part of the Winter Olympics programme since the 1936 Winter Games. Competitions are held for both women and men. With downhill, super-G, giant slalom, slalom and alpine combination, five disciplines are currently part of the Olympic program.

After Christoph Raschka presented the somatotypes of these interesting popular disciplines in skiing in *Papers on Anthropology* [54] in 2019, this paper continues to present additionally the body composition and the underlying nutritional and sports physiological knowledge in skiing.

GENERAL BASICS OF SPORTS NUTRITION FOR SKIERS

In principle, the increased need for fluids and energy is the most important aspect of athlete nutrition compared to the nutrition of less active persons [50–53].

A carbohydrate-based (at least 50%), fat-controlled (max. 30%), varied, wholesome mixed diet represents the ideal basic diet regardless of the winter sports discipline because the energy supply through carbohydrates represents the limiting factor under stress [58, 59, 69].

The additional need for nutrients is also considered to be satisfied if the additional energy requirement is covered by such a mixed diet. It increases proportionally. Both the correspondingly higher need for proteins and carbohydrates (absolute requirement) and for micronutrients (vitamins and minerals) can be satisfied by common foods [2, 3].

In addition to basic nutrition, special requirements are particularly useful for endurance athletes such as cross-country skiers, such as super-maximally filled glycogen stores, short regeneration times, correct meal timing or appropriate weight specifications for ski jumping.

Through appropriate training, the organism can efficiently adapt the energy-providing systems and thus change the proportions of energy carriers (carbohydrates, fat) but not the amount of the energy itself [2, 3].

The recreational skier only needs to take care of an adequate supply of fluids and energy before, possibly during and after the sport.

Athletes also pay attention to energy balance. Finally, a deficiency could have a fatal effect on performance and possibly affect health negatively in the long run: as a result of weight loss, muscle mass is also reduced. As a result, the body becomes more susceptible to diseases and needs longer regeneration times. Bone density is also affected [2, 3, 25].

However, energy balance can usually be assumed [58, 59] if body weight is constantly within the recommended range (with completed growth in height). For correct evaluation of weight, the body mass index (BMI in kg/m^2) is suitable for amateur athletes (the standard range for women is 19–24 kg/m^2; for men 20–25 kg/m^2) [58, 59]. In the case of muscular athletes, the BMI unfortunately no longer allows a realistic assessment. In ski jumping, a lower BMI prolongs the flight phase, resulting in greater distances [21, 34, 35, 66].

For competitive athletes (average 1–3 hours per day, energy consumption by sport: 1,000– 3,000 kcal/day), in principle, the regular D-A-CH reference values apply [8, 58, 59] in nutrient distribution (Table 1).

Table 1. Main nutrient distribution according to load intensity (data as energy percentage, [2, 3, 25, 48–53])

Training Intensity	Training Volume	Carbohydrates	Fat	Protein
hobby sports	30–60 min/d 3–4× per week	50% 4 g/kg/d	max. 30%	12–15% 0.8-1.0 g/kg/d
moderate-intensity training	2–3 h/d 5–6× per week	55–65% 5–8g/kg/d	max. 30%	15% 1.0–1.5 g/kg/d
high-intensity training	3–6 h/d 5–6× per week	8–10g/kg/d	max. 30%	1.5–1.7 g/kg/d

An athlete with a moderately high energy intake (e.g. 4000 kcal) already achieves the necessary intake of 500 g carbohydrates per day with a 50% carbohydrate content. Conversely, with a very low energy intake (< 2000 kcal) the intake for an optimal carbohydrate supply must be above 60% [2, 3].

While cross-country skiing is clearly one of endurance sports in terms of sports groups, some authors [24] consider ski jumping and alpine skiing fast-strength sports, others [36] technical (acrobatic) sports.

Cross-country skiers, like all well-trained athletes, can burn body fat earlier and to a greater extent. The glycogen stores are spared. This enables the athlete to keep his/her stress intensity at a higher level for longer or to save reserves for an intermediate or final sprint [29]. With appropriate individual tolerability, the fat metabolism can also be trained via a moderate fasting training. Here, running with an empty stomach (morning) in the training phase is recommended [13]. The storage capacity of glycogen in the muscles and liver can be increased by regular endurance load and the corresponding dietary behaviour [7].

SPECIAL SPORTS PHYSIOLOGICAL ASPECTS OF ENERGY METABOLISM, FLUID AND MINERAL BALANCE AND VITAMIN METABOLISM IN SKIING

Optimized training conditions also allow the athlete to continuously perform (aerobic performance) at a higher load level. For this purpose, the so-called "aerobic-anaerobic threshold" (endurance performance limit) from which the body must gain increasingly anaerobic energy is shifted. This value can be expressed as a percentage of the maximum oxygen uptake, i.e., % of VO_2max [22, 69].

Carbohydrates as an energy source [29] are required for stress intensities of 75% VO_2max, which is a typical training intensity in many endurance sports.

Carbohydrates are known to provide the body with faster energy (energy flow rate) and require less oxygen to oxidise than is the case with fats. Their energy yield per litre of oxygen is 7% more economical compared to fat [69].

An important prerequisite for such intensive and long-lasting physical work for over 90 minutes is a stable blood sugar level and thus a high-carbohydrate diet at least one day before the competition.

The proven advantages of carbohydrate loading (supercompensation), a nutritional technique for classic endurance loads, also apply to cross-country skiing [48–53]. One week before a competition and after an intensive training session, the athlete reduces his/her training load to 75% of the maximum oxygen uptake. In the first three days, a normal mixed diet (~350 g carbohydrates per day, 4 g/kg body weight) is maintained, and then for the next three days the athlete switches to a very high-carbohydrate diet (over 500 g per day, 10g / kg body weight) before the competition. With this, the glycogen content can be raised above the normal value and super-compensated. This technique is useful for competitions with intensive endurance exercise (> 90 min, 65–85% of VO_2max) [59].

Untrained people can produce approximately 0.8 litres of sweat per hour, while trained athletes can produce 2–3 litres [24]. A premature drop in performance, concentration and coordination disorders as well as overheating threaten from a fluid loss of 2% of the total body water [61].

Unfortunately, the feeling of thirst is not a sufficient marker for the required water intake in sport, so that the athlete would spontaneously drink only about 2/3 of the water lost through sweat. Furthermore, according to [71], at the same ambient temperature the sweat emissions per hour are between 0.5 and 1.7 l. The individual amount of sweat can easily be determined by means of weight controls. In the regeneration phase, one should take in 1.5 times the amount of sweat lost [61]. Salt content of 1–2 g per litre is recommended for a sports drink. On the other hand, potassium, magnesium, calcium, iron, copper and zinc as well as water-soluble vitamins and amino acids are lost through sweat only in small amounts. For all exercise intensities of up to one hour duration, sodium-rich water without carbonic acid is sufficient.

Juice spritzers (3 parts of water to 1 part juice; alternatively: mineral water plus solid food) or isotonic beverages (with maltodextrin) are suitable for stress lasting for several hours. In order to minimize stomach irritation, apple, grape or currant juice (nectar) spritzers are preferable to orange or grapefruit juice because of their lower fruit acid content. Vitamin additives or sweeteners are unnecessary in sports drinks. Before the actual competition, however, all drinking strategies, drinks and also temperatures of the drink should be tried out for individual tolerance [51–53].

Due to their hypertonic concentration and deficient electrolyte content, energy drinks are not suitable for use before or during sport. Only with 3 mg of caffeine per kg of body weight (approx. 2 cups of coffee), it is possible to optimize the use of fat through caffeine, which is desired before endurance competitions [5].

Vitamins A, C, E and B_6 (with high protein consumption) as well as the minerals calcium, magnesium, iron and zinc can be critical in the supply status of competitive athletes. In Germany, the iodine supply is often still suboptimal regardless of physical activity. This can lead to a drop in performance [58, 59].

Since the higher need is actually compensated by the increased food intake with a balanced mixed diet, there is, in principle, no over-proportional need for individual vitamins in athletes. Basically, vitamin preparations should not contain more than 100% of the daily recommendation. Unless there is a specific deficiency, preference should be given to multivitamin preparations over individual vitamins in the event of an unbalanced diet.

HIGH ALTITUDE PHYSIOLOGICAL ASPECTS OF SKIING

However, special physiological requirements can arise at high altitudes (see Fig. 1). The performance differs depending on the stay at high (3000–4500 m), very high (4500–6000 m) and extreme (> 6000 m) heights [50–53].

Respiratory rate increases from the altitude of 1500 m [46]. Maximum oxygen uptake decreases by 1% for every 100 meters of altitude. As maximum oxygen uptake is already 15% lower from 3000 m altitude, a drop in performance is clearly noticeable there. At 4500 m altitude it is only 65% compared to the lowlands. Due to various factors (including dry, "thin" air, increased breathing rate, increased diuresis), 3–5 litres per day should be drunk at high altitudes (1.5 l plus 2 g of table salt immediately after exercise) in order to prevent headaches and other symptoms of altitude sickness (if possible, with daily weight control for longer stays at altitude).

When skiing (snowshoeing, ski touring, etc.), it should be noted that an ascent of 100 meters in altitude alone requires an additional 100–150 kcal.

With moderate activity, the additional energy requirement at high altitudes compared to the sea level is estimated to be 250–290 kcal per day for men and 180–200 kcal per day for women [50–53].

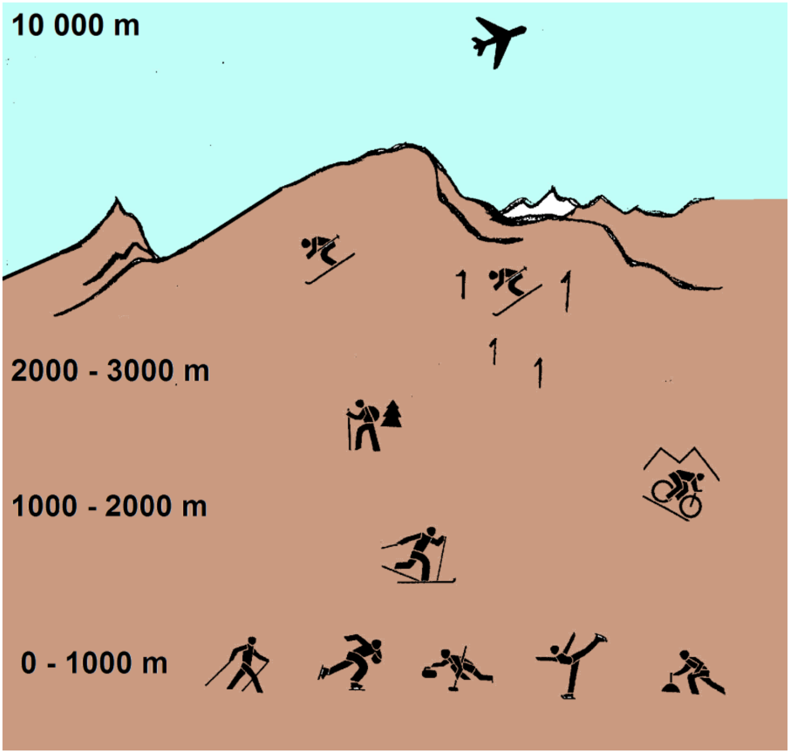

Figure 1. Winter sports at high altitude, redrawn and modified from [27]

EATING DISORDERS IN SKIING

An eating disorder is a particular risk for weight-focused ski jumpers. Here the boundaries from the sports-induced eating disorder, the so-called anorexia athletica, to anorexia nervosa and bulimia can run fluidly. However, anorexia athletica is often not yet classified as a mental illness, because the athlete can still determine his body weight depending on the respective training phase. Since 2012, a BMI of at least 21 kg/m² including suit and shoes has been a condition for the ski jumper to be able to use the full length of the ski (145% of the body height). Otherwise shorter skis have to be used, which reduces the wing area and is intended to reduce the jump distance as a penalty.

SPECIAL ENERGY METABOLISM IN SKIING

According to [19], top athletes in cross-country skiing can liberate 170–210 kJ/min (40–50 kcal/min) in a dominant anaerobic manner within 2–3 minutes.

According to [20], the average maximum oxygen uptake of 451 cross-country skiers on the bicycle ergometer was almost 70 ml/kg/min. In addition to the psychological stress, this was primarily attributable to the above-average static musculature stress.

Williams [69] provided a weight-related table showing the approximate calorie consumption per minute for various forms of exercise and sports; the data concerning alpine skiing and cross-country skiing are given in Table 2. They do not only express additional consumption due to physical activity but also contain the calories that would have been consumed in the same time during rest. In addition, the numbers only concern the pure exercise time. Breaks or interruptions are not included.

It should also be noted that the corresponding energy consumption is modified by numerous personal as well as external factors (for cross-country skiing, for example, the outside temperature, the friction resistance of the snow, the technique, the height profile of the route and the headwind). According to Williams [69], it was not possible to continuously list all possible body weights, so that according to his statements, it is justified to interpolate between the values or to use the number given for the closest body weight. There is also no differentiated consideration of the sexes.

Table 2. Calorie consumption per minute for alpine skiers and cross-country skiers with different body weights at different speeds [69]

Sport		**Cross-country skiing**		
Body weight	**Alpine skiing**	4 km/h 15min/km	6 km/h 10 min/km	8 km/h 12 min/km
45 kg	6.5	5.0	6.5	7.7
48 kg	6.8	5.2	6.8	8.0
50 kg	7.2	5.5	7.2	8.4
52 kg	7.5	5.7	7.5	8.8
55 kg	7.8	6.0	7.8	9.2
57 kg	8.2	6.2	8.2	9.6
59 kg	8.5	6.5	8.5	10.0
61 kg	8.8	6.7	8.8	10.4
64 kg	9.2	7.0	9.2	10.8

Sport		Cross-country skiing		
Body weight	**Alpine skiing**	4 km/h 15min/km	6 km/h 10 min/km	8 km/h 12 min/km
66 kg	9.5	7.2	9.5	11.1
68 kg	9.9	7.5	9.9	11.5
70 kg	10.2	7.8	10.2	11.9
73 kg	10.5	8.0	10.5	12.3
75 kg	10.9	8.3	10.9	12.7
77 kg	11.2	8.5	11.2	13.1
80 kg	11.5	8.8	11.5	13.5
82 kg	11.9	9.0	11.9	13.9
84 kg	12.2	9.3	12.2	14.3
86 kg	12.5	9.5	12.5	14.7
89 kg	12.9	9.8	12.9	15.0
91 kg	13.2	10.0	13.2	15.4
93 kg	13.5	10.3	13.5	15.8
95 kg	13.8	10.6	13.8	16.2
98 kg	14.2	10.8	14.2	16.6
100 kg	14.5	11.1	14.5	17.0

NUTRIENT ABSORPTION IN SKI SPORTS

Nutrient absorption in cross-country skiing

Ellsworth et al. [11] collected the food intake data of 13 male and 14 female members of the US Nordic Ski Team during a year.

The daily energy intake of men (average height 177 cm, weight 73 kg) fluctuated, depending on the training phase, between 3492 ± 948 and 5450 ± 1188 kcal (i.e., on average from 49 to 76 kcal per kg body weight), the corresponding values for women (average height 163 cm, weight 57 kg) were between 2414 ± 340 and 3963 ± 688 kcal (i.e., on average from 42 to 71 kcal per kg).

In a survey of 16 young cross-country skiers (6 boys, 10 girls), Pařízková [42] documented a corresponding daily energy intake of 15.1 ± 6.4 MJ for the boys (age: 16.6 ± 1.4 years; height 180.7 ± 3.1 cm; weight: 69, 3±3.1 kg) in the normal training phase and 22.8 ± 3.8 MJ in the pre-competition period. The corresponding values for the girls (age: 15.7±1.2 years; height 164.1±5.6 cm; weight: 49.3±7.3 kg) were 11.4±3.8 MJ and 17.4±3.0 MJ respectively.

The average main nutrient distribution for both sexes [11] is illustrated in the following two graphs (Fig. 2)

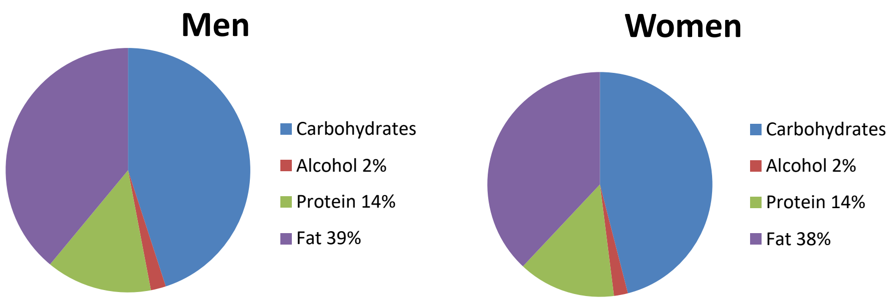

Figure 2. Average daily main nutrient distribution among the male and the female members of the US Nordic Ski Team over the course of the year [11]

With regard to micronutrients, all participants met the recommendations for daily intake of vitamin C, thiamine, riboflavin, niacin and calcium. Only in women, the iron intake was marginally lower [11].

Nutrient uptake in alpine skiing

Meyer et al. [30, 31] collected the nutrient uptake data (4-day protocols) of 10 alpine racers from Switzerland during the 7-month preparation for the winter season (2–6 hours of fitness and/or ski training per day).

Remarkably, the energy consumption did not increase in parallel to the estimated energy consumption (calculated on the basis of 4-day 24-hour activity records). While the energy consumption increased by about 1500 kcal until the actual snow practice, the energy intake increased with the diet only by about 230 kcal per day. This also applies to carbohydrate intake – the values for snow training fluctuated between 5.4 and 7.2 g/kg/day. Meyer et al. [30, 31] had also collected data on Austrian male alpine skiers but only for the first phase of preparatory training at home and received an almost identical value for carbohydrate intake averaging 6.4 g/kg/day. Ski training itself leads to a depletion of muscle glycogen as demonstrated by muscle biopsies on recreational and competitive skiers in the late 1970s [40, 68]. 20% of the muscle fibres are depleted of glycogen after just one day of skiing. Glycogen replenishment is still not complete in the following morning [68].

The situation with multiple days of skiing without sufficient carbohydrate intake is likely to be even more serious, which would then also mean a potential drop in performance and an increasing risk of accidents. Brouns et al. [6] observed that most skiing accidents happened late in the day when the skiers were tired, and glycogen in muscle fibres was depleted.

According to [30, 31], the percentage of energy intake in fat varied between 32 and 35% for female alpine skiers without any change over the above training phases, while protein intake varied between 1.4 and 1.7 g/kg/day. According to a survey of 83 ski racers (Switzerland, Austria, USA), only 42% consume drinks containing carbohydrates and 25% energy bars containing carbohydrates [30, 31].

The iron status of female athletes is critical/suboptimal: 30% of alpine skiers have too low serum ferritin concentrations (<20 μg/l) but still without iron deficiency anaemia (Hb > 12 g/dl, [30, 31]). This agrees with the findings of [51] who described iron deficiency of 36% in female alpine skiers from Norway, while all serum ferritin concentrations in male skiers were within the normal range. The iron balance of female skiers should therefore be a regular focus of sports medical care.

With regard to the emergence of a special cohort of women who practise a sport which is known to influence energy availability, the menstrual cycle and bone density, and which then manifests itself clinically in eating disorders, amenorrhea and osteoporosis (in the worst case even in stress fractures), Manore [26] reports on the results of a survey of 39 alpine elite and young female racers that 23% of them were classified as oligo- or amenorrhoeic.

BODY COMPOSITION OF SKIERS

When comparing the parameters of body composition (Table 3), it must always be remembered that different methods of determining the body fat percentage have been used in the corresponding studies, and that possible differences do not represent a development over time but can also have methodological reasons. When using the table as a reference value, after reading the corresponding original article, attention should be paid to compatibility with the determination method used in your own practice (institute, hospital, etc.) (e.g., near-infrared method, BIA, calipermetry).

Table 3. Body composition in cross-country skiing, alpine skiing, ski jumping and Nordic combination

Male cross-country skiers	N	Age (years)	Fat %	LBM	Authors
Soviet elite	65	18–25	7.2%	63.9 kg	[45]
Czechoslovak NT	6	25.9	7.4%	68.8 kg	[64]
US NT	7	26.3	8.9%	?	[16]
US NT	7	21.3	12.0%	?	[17]
Czechoslovak NT	6	25.7	–	?	[41–43]
US NT	11	22.8	7.2%	67.1 kg	[61]
Finnish NT	17	25.6	10.2%	60.3 kg	[23, 55, 56]
Toronto College	10	21.2	12.5%	58.2 kg	[38, 39]
US NT	10	22.7	7.9%	67.7 kg	[18]
Czechoslovak Club	9	23.6	4.8%	66.0 kg	[63]
US Elite	9	32.3	12.7%	?	[32]
Czechoslovak youngsters	6	16.6	5.2%	?	[44]
Croatian youngsters	15	17.1	6.4%	62.6	[28]
Female cross-country skiers	**n**	**Age (years)**	**Fat %**	**LBM**	**Authors**
US NT	2	24.0	16.7%	?	[17]
US NT	5	23.5	16.1%	48.6 kg	[61]
Finnish NT	5	24.3	21.8%	47.0 kg	[23, 55, 56]
Soviet NT	?	?	16.3%	?	[9]
Soviet A-Team	5	19.8	16.6%	?	[9]
Soviet B-Team	5	19.8	22.6%	?	[9]
US – Team	10	20.2	15.7%	45.6 kg	[18]
Finnish Juniors	15	17.6	22.7%	?	[55, 56]
Czechoslovak youngsters	10	15.7	10.6%	?	[44]
Male alpine skiers	**n**	**Age (years)**	**Fat %**	**LBM**	**Authors**
Finnish NT	6	21.2	14.1%	60.8 kg	[23, 55, 56]
US NT	12	21.8	10.2%	67.7 kg	[18]
US Elite	5	22.0	9.7%	64.6 kg	[12]
Canadian Juniors	9	16.5	11.0%	?	[62]
International Downhill	52	22.2	11.9%	66.5 kg	[4]
International Slalom	53	22.2	11.4%	63.1 kg	[4]
Internat. Giant Slalom	58	22.1	11.4%	63.5 kg	[4]
Austrian World Cup	28	27.6	15.8%	73.3 kg	[37]
Internat. Elite Slalom	17	22.5	12.9%	70.3 kg	[1]

Male alpine skiers	**n**	**Age (years)**	**Fat %**	**LBM**	**Authors**
Internat. Elite Downhill	26	25.8	14.5%	74.4 kg	[1]
Internat. Elite Combination	15	22.5	13.4%	71.8 kg	[1]
German NT	69	19.3	10.0%	69.7 kg	[14]
Spanish Juniors NT	18	17.8	11.8%	64.9 kg	[15]
Spanish Seniors NT	7	22.5	11.9%	67.4 kg	[15]
Japanese High School Elite	41	17.3	11.9%	59.9 kg	[33]
International Juniors	20	17.7	10.9%	67.3 kg	[66]
International Elite	49	24.9	12.6%	74.7 kg	[66]
Female alpine skiers	**n**	**Age (years)**	**Fat %**	**LBM**	**Authors**
US NT	13	19.5	20.6%	46.6 kg	[18]
US Elite	8	20.8	16.2%	42.1 kg	[12]
Austrian World Cup	20	25.2	24.5%	49.2 kg	[37]
Internat. Elite Slalom	11	21.3	24.4%	49.2 kg	[1]
Internat. Elite Downhill	9	25.6	26.7%	50.8 kg	[1]
Internat. Elite Combination	6	20.8	23.3%	51.4 kg	[1]
German NT	74	18.5	19.6%	52.7 kg	[14]
Spanish Juniors NT	13	18.0	17.6%	45.5 kg	[15]
Spanish Seniors NT	7	22.5	17.4%	49.1 kg	[15]
International Juniors	36	17.0	21.2%	47.9 kg	[66]
International Elite	19	24.6	22.7%	52.8 kg	[66]
Skijumpers (male)	**n**	**Age (years)**	**Fat %**	**LBM**	**Authors**
Finnish NT	9	22.2	14.3%	59.7 kg	[23, 55, 56]
US Elite	?	?	12-16%	?	[69]
Finnish Elite	21	19.7	8.6%	?	[47]
Nordic Combination (male)	**n**	**Age (y.)**	**Fat %**	**LBM**	**Authors**
US NT	9	21.7	8.9%	64.1 kg	[18]
Finnish NT	5	22.9	11.2%	62.0 kg	[23, 55, 56]

NT = national team; LBM = lean body mass

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